

# INTRODUCING OF PARASITIC ELEMENTS TO SHORT BACKFIRE ANTENNA FOR RADIATION PATTERN IMPROVEMENT

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## **ABSTRACT**

Short backfire antenna has an enclosed structure with two reflectors on top of each other conventionally short backfire antenna is characterized by gain of above 10 dB, making it attractive for handheld radio monitoring and other man-portable applications. However, a microstrip patch fed short backfire antenna had a broad E-plane radiation pattern main lobe, leading to a loss of gain and low aperture efficiency. Using commercially available CST microwave software the aim of this project was to design a short backfire antenna which has symmetric E&H planes radiation pattern. Adding six parasitic wires inside the cavity of a short backfire was found to narrow the E-plane radiation pattern main lobe, making it more like the H-plane radiation pattern and increasing the peak gain making it to around 15.5 dB. A single proof of concept antenna was built at 2.4 GHz with a microstrip patch fed with coaxial probe and have shown equalized principle planes.

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# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 Overview**

Microstrip patch antennas have been considered as one of the most promising candidates in government, commercial and defense applications, due to their attractive advantages such as simplicity of the structure, low profile, light weight, easy fabrication and also it can be used to in a range of frequencies from 1GHz to 100 GHz [1]. Microstrip patch antennas have been used in many commercial and military applications including Radar, Mobile communications, satellite communications, and Wireless Local Area networks (WLANs). The Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side [2]. The characteristic of the rectangular Microstrip antenna is defined mainly by its geometry and the material properties from which it was made [3] on the other hand the electrical properties of the antenna such as Wide Bandwidth, High efficiency and radiation properties must be satisfied to enhance the performance of the antenna [3]. This Microstrip patch will now be used as a radiating patch of a Short backfire antenna that will be designed in this project.

The short backfire antenna was first conceived by Ehrenspeck in 1960s [4], has received much interest for its beneficial characteristics such as compactness, simplicity

of construction, high gain and so on. The conventional Short backfire antenna consists of two parallel plate reflectors with different dimensions (a big and small reflector), spaced a distance about  $\lambda/2$  apart and the commonly feeds used includes rectangular waveguides, dipole feed and Microstrip feed line. The Microstrip short backfire antenna combines a Microstrip-type element (patch element) with a backfire cavity [4]. In spite of the many advantages that patch antennas have in comparison to conventional antennas, they suffer from certain disadvantages. The major drawbacks of such antennas are the narrow bandwidth and low beam directions. Since the short backfire Microstrip patch is a directional antenna it radiates along the broadside direction with a non-uniform radiation beams where the E-plane pattern is always wider than that in H-plane [5]. Therefore to achieve E-plane and H-plane patterns that are almost symmetry parasitic elements are going to be introduced as well as to increase the performance of this antenna.

## 1.2 Problem Statement

The Microstrip short backfire antenna is one of the most preferable for wireless communications, especially when a built-in antenna is required. Since the Microstrip short backfire antenna can be made with a very thin and compact structure, it can easily match various types of portable units. Medium gain antenna was needed for use during the development of the narrow beamwidth antennas, a lot of researches have been done on this matter and multiple techniques of gain improvement of microstrip antennas have been done, however due to excitation of surface waves, patch antenna suffers from reduced gain.

Moreover previous works have shown that Microstrip patch fed short backfire antenna had a broad E-Plane radiation pattern main lobe leading to a loss of gain and low aperture efficiency. In other words non-uniform radiation beams the E-plane pattern is always wider than that in H-plane. To overcome this problem, this project will introduce parasitic elements by placing inside the cavity of the Microstrip Short backfire antenna to improve the gain.

### **1.3 Objectives of Project**

The objectives of this project are:

- I. To design Microstrip short backfire antenna operating at the resonance frequency 2.4 GHz.
- II. To study how a parasitic elements increase the gain of the short backfire antenna.
- III. To analyze and synthesize the effect of parasitic elements on performance of the antenna.

### **1.4 The Scope of The project**

This project is divided into three major phases:

- I. To design a single Microstrip short backfire antenna with parasitic elements that operates at 2.4 GHz with suitable gain.
- II. To simulate the parameters of the antenna such as radiation pattern and return loss by using CST microwave studio followed by the fabrication of the antenna with FR4 dielectric substrate.
- III. The result of Radiation pattern of the Microstrip short backfire antenna is limited to simulations only.

## **CHAPTER 2**

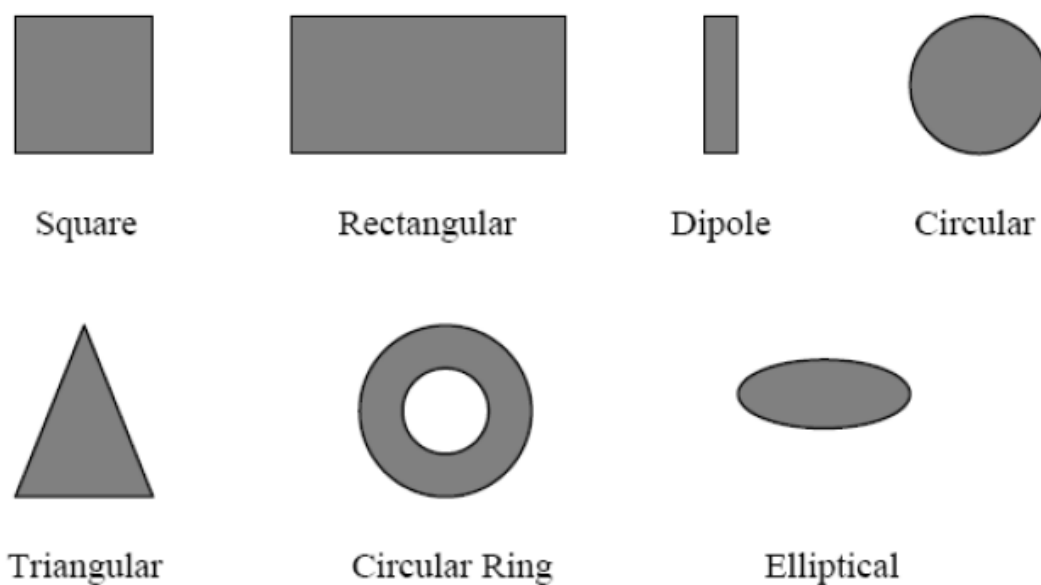
### **LITERATURE REVIEW**

#### **2.1 Introduction**

Microstrip patch antennas were first proposed in the early 1970s and since then a plethora of activity in this area of antenna engineering has occurred, probably more than in any other field of antenna research and development. Microstrip patch antennas have several well-known advantages over other antenna structures, including their low profile and hence conformal nature, light weight, low cost of production, robust nature, and compatibility with microwave monolithic integrated circuits and optoelectronic integrated circuits technologies. Because of these merits, forms of the Microstrip patch antenna have been utilized in many applications such as in mobile communication base stations, space borne satellite communication systems, and even mobile communication handset terminals [6]. Despite the previously mentioned features, Microstrip patch antennas suffer from several inherent disadvantages of this technology in its pure form, namely, they have small bandwidth and relatively poor radiation efficiency resulting from surface wave excitation and conductor and dielectric losses.

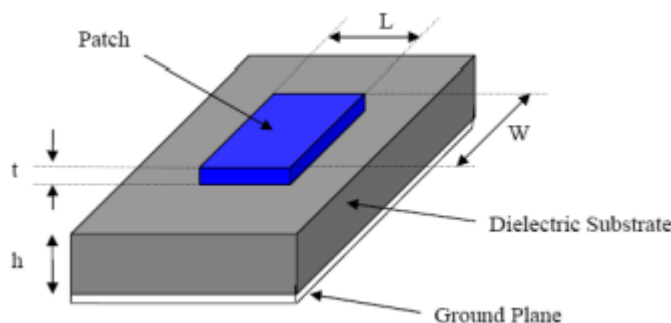
## 2.2 Microstrip Patch Antenna

Microstrip antennas are attractive due to their light weight, conformability and low cost. These antennas can be integrated with printed strip-line feed networks and active devices. This is a relatively an interesting area of antenna engineering. The radiation properties of micro strip structures have been known since the mid 1950's [7]. There are different types of Microstrip antennas which are classified based on their physical parameters. Different types of antennas have many different shapes and dimensions. There are several shapes that can be used as the radiating patch. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other shape [8].



**Figure 2.1** commonly used shapes of Microstrip patch antenna [11]

A Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Fig. 2.1.



**Figure 2.2** Basic microstrip patch antenna [7]

The patch is generally made of conducting material such as copper or gold and can take any possible shape of the shapes shown in above figure 2.1 and also any other shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. Microstrip patch antennas have many advantages when compared to conventional antennas. As such, they have found usage in a wide variety of applications ranging from embedded antennas such as in a cellular phone, pagers, telemetry and communication antennas on missiles and in satellite communications. Some of their principal advantages discussed by [8] and James and Hall [9] are:

- Light weight and low volume
- Low fabrication cost, hence can be manufactured in large quantities
- Supports both, linear as well as circular polarization
- Mechanically robust when mounted on rigid surfaces.

In spite of the many advantages, these antennas also suffer from a number of disadvantages. Some of them have been discussed by Kumar and Ray in [9] and Garg. In [10] and they are given below:

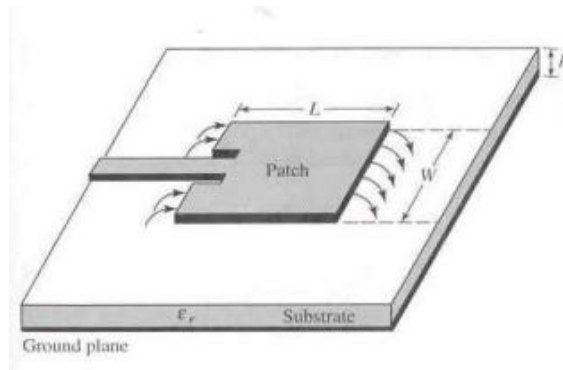
- Narrow bandwidth
- Low efficiency
- Low gain.

## 2.3 Feeding Techniques for the Patch Antenna

Microstrip antennas are fed by a variety of methods that are generally classified into two main categories, namely, contacting and non-contacting. In the contacting method the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting method, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch [8]. The four most widespread feed techniques used are the Microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes). Microstrip Feed line is going to be used in designing this rectangular patch antenna.

### 2.3.1 Model Microstrip line feed

In this kind of feed technique, a conducting strip is connected directly to the edge of the Microstrip patch the conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.



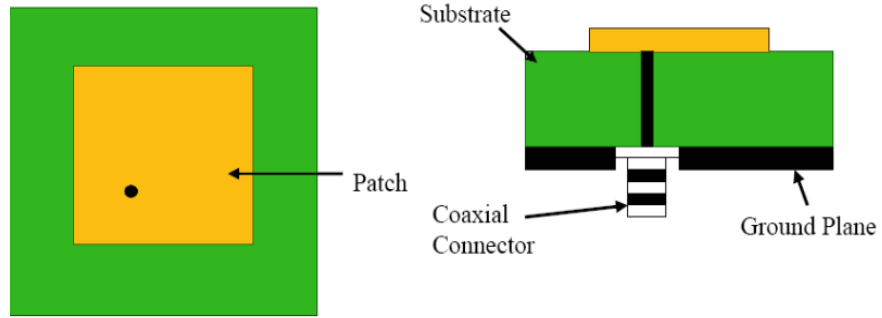
**Figure 2.3: Microstrip feed line [8]**

Most of the cases the inset cut is preferred over the edge feed. The purpose of inset cut is to match the impedance of the feed line to the patch without the need for any additional matching element. It is an easy feeding technique that is easy to fabricate and provides simplicity in modeling as well as impedance matching. However as

the thickness of the dielectric substrate being used increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna [8]. The feedline radiation also leads to undesired cross polarized radiation.

### 2.3.2 Coaxial Feed

The coaxial feed also known as probe feed is a very common contacting scheme of feeding patch antennas, the probe or feeding pin is usually the inner conductor of a coaxial line [7]. The probe position provides the impedance control in a similar manner to inserting the feed for an edge-fed patch. Because of the direct contact between the feed transmission line and the patch antenna, probe feeding is referred to as a direct contact excitation mechanism.



**Figure 2.4:** Probe-fed Microstrip top view (left) and side view (Right) [7]

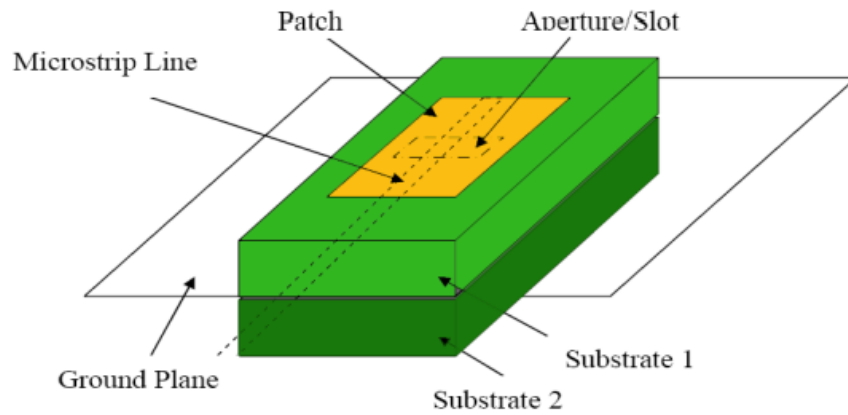
The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ( $h > 0.02\lambda_0$ ). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems [7]. It is seen as above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. Therefore non-contacting



techniques have been developed. The two non-contacting feeding techniques are aperture coupled feed and proximity coupled feed.

### 2.3.3 Aperture Coupled Feed

Because of the shortcomings of the direct contact feeding techniques, namely, the small inherent bandwidth and the detrimental effect of surface waves, noncontact excitation mechanisms were introduced. The first of these is the aperture-coupled patch.

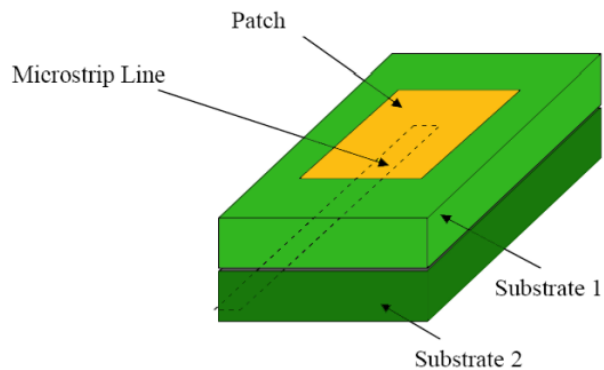


**Figure 2.5:** Aperture Coupled Feed [7]

The coupling aperture is usually centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch [8]. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

### 2.3.4 Proximity Coupled Feed

The second form of noncontact fed patches created to overcome the shortcomings of the direct contact fed patches is the proximity-coupled patch. This type of feed technique is also called the electromagnetic coupling scheme.



**Figure 2.6: Proximity Coupled Feed [7]**

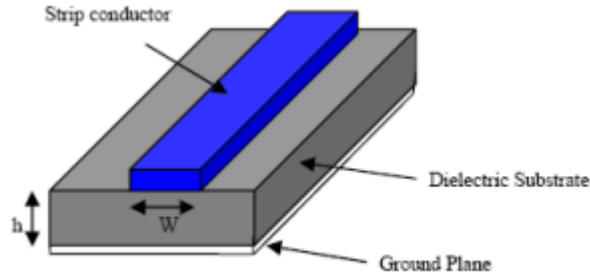
The microstrip antenna consists of a grounded substrate where a microstrip feed line is located [8]. Above this material is another dielectric laminate with a microstrip patch etched on its top surface. Please note there is no ground plane separating the two dielectric layers. The power from the feed network is coupled to the patch electromagnetically, as opposed to a direct contact. This is why this form of microstrip patch is sometimes referred to as an electromagnetically coupled patch antenna. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides higher bandwidth in comparison to the other feeding techniques (as high as 13%) [10], due to overall increase in the thickness of the microstrip patch antenna. Matching can be achieved by controlling the length of the feed line and the width-to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna.

## 2.4 Methods of Analysis for Patch Antennas

Methods that are popular for analyzing the patch antennas are: The Transmission Line model, the cavity Model, and the Full Wave model. The Transmission line model is the easiest of all, less accurate and difficult to model coupling, cavity model is more accurate but more complex, and the full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling [11]. These gives less insight as compared to the two models mentioned above and are far more complex in nature.

### 2.4.1 Transmission Line Model

Basically this model represents the Microstrip antenna by two slots separated by a low impedance  $Z_c$  transmission line of length  $L$ . The Microstrip is essentially a non-homogeneous line of two dielectrics, typically the substrate and air [12].



**Figure 2.7:** Microstrip Line [5]

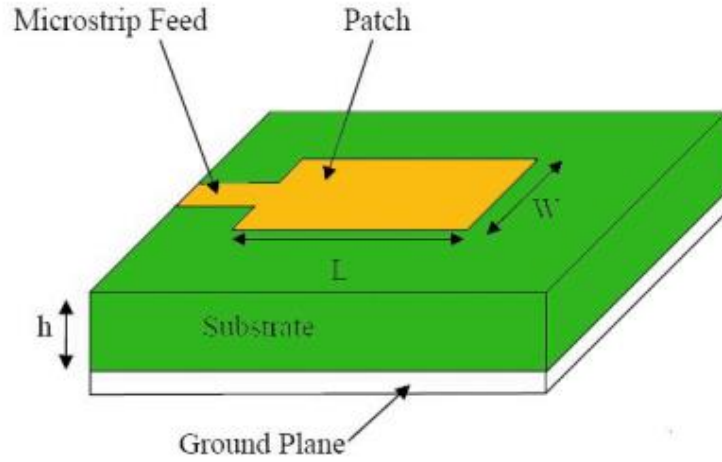
Most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse-electric-magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. For the quasi TEM mode, we find that

$$u_p = \frac{c}{\sqrt{\epsilon_{eff}}} \quad (2.1)$$

$$\beta = \omega \sqrt{\mu_0 \epsilon_0 \epsilon_{eff}} = k_0 \sqrt{\epsilon_{eff}} \quad (2.2)$$

where  $u_p$  is the phase velocity, and  $\beta$  is the wave constant of the line.

Hence, an effective dielectric constant ( $\epsilon_{eff}$ ) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ( $\epsilon_{eff}$ ) is usually a number that is between  $1 < \epsilon_{eff} < \epsilon_r$  because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air [6].



**Figure 2.8:** Microstrip Patch antennas [7]

Figure above shows a rectangular Microstrip patch antenna of length  $L$ , width  $W$  resting on a substrate of height  $h$ . The co-ordinate axis is selected such that the length is along the  $x$  direction, width is along the  $y$  direction and the height is along the  $z$  direction.

The value of ( $\epsilon_{eff}$ ) is slightly less than  $\epsilon_r$ , because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air. The expression for  $\epsilon_{eff}$  is given by Balanis [8] as:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}} \quad (2.3)$$

Where  $\epsilon_{eff}$  denotes effective dielectric constant,  $\epsilon_r$  stands for dielectric constant of substrate,  $h$  represents height of dielectric substrate, and  $W$  identifies width of the patch. Given the dimensions of the microstrip, the characteristic impedance of the line can be calculated as [8]

$$Z_0 = \frac{60}{\sqrt{\epsilon_{eff}}} \ln \left( \frac{8d}{w} + \frac{w}{4d} \right) \quad \frac{w}{d} < 1 \quad (2.4)$$

Or

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_{eff}} \left[ \frac{w}{d} + 1.393 + 0.667 \ln \left( \frac{w}{d} + 1.444 \right) \right]} \quad \frac{w}{d} > 1 \quad (2.5)$$

After calculating the characteristic impedance the line width can be calculated as

$$\frac{W}{d} = \frac{8e^A}{e^{2A} - 2} \quad \frac{w}{d} < 2 \quad (2.6)$$

$$\frac{w}{d} = \frac{2}{\pi} \left[ B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left( \ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r} \right) \right], \frac{w}{d} > 2 \quad (2.7)$$

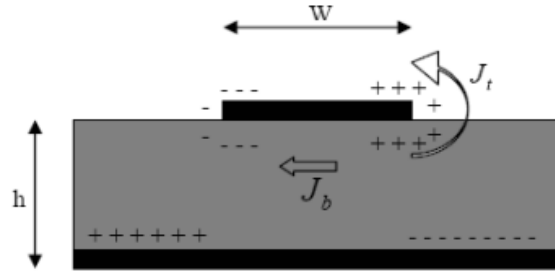
$$\text{where, } A = \frac{Z_0}{60} \sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1} \left( 0.23 + \frac{0.11}{\epsilon_r} \right) \text{ and } B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}} \quad (2.8)$$

### 2.4.2 Cavity Model

Although the transmission line model discussed in the previous section is easy to use, it has some inherent disadvantages. Specifically, it is useful for patches of rectangular design and it ignores field variations along the radiating edges. These disadvantages can be overcome by using the cavity model. A brief overview of this model is given below. In this model, the interior region of the dielectric substrate is modeled as a cavity bounded by electric walls on the top and bottom. The basis of this assumption is the following observations for thin substrates [13].

- Since the substrate is thin, the fields in the interior region do not vary much in the  $z$  direction, i.e. normal to the patch.
- The electric field is  $z$  directed only, and the magnetic field has only the transverse components  $H_x$  and  $H_y$  in the region bounded by the patch metallization and the ground plane.

This observation provides for the electric walls at the top and the bottom.



**Figure 2.9:** Charge distributions along the Microstrip patch

Consider Fig. 2.9 shown above. When the Microstrip patch is provided power, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane. This charge distribution is controlled by two mechanisms which are attractive mechanism and a repulsive mechanism as discussed in [17].

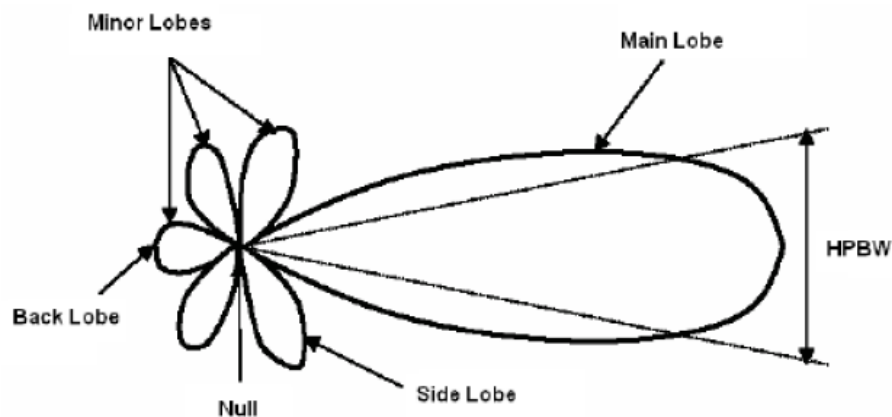
The attractive mechanism is between the opposite charges on the bottom side of the Patch and the ground plane, which helps in keeping the charge concentration intact at the bottom of the patch. The repulsive mechanism is between the like charges on the bottom surface of the patch, which causes pushing of some charges from the bottom, to the top of the patch. As a result of this charge movement, currents flow at the top and bottom surfaces of the patch. The cavity model assumes that the height to width ratio (i.e. height of substrate and width of the patch) is very small and as a result of this the attractive mechanism dominates and causes most of the charge concentration and the current to be below the patch surface. Much less current would flow on the top surface of the patch and as the height to width ratio further decreases, the current on the top surface of the patch would be almost equal to zero, which would not allow the creation of any tangential magnetic field components to the patch edges [14]. Hence, the four sidewalls could be modeled as perfectly magnetic conducting surfaces. This implies that the magnetic fields and the electric field distribution beneath the patch would not be disturbed.

## 2.5 Antenna Parameters

An antenna is a device that is used to transfer guided electromagnetic waves to radiating waves in an unbounded medium, usually free space, and vice versa (i.e., in either the transmitting or receiving mode of operation). Thus For designing a perfect antenna there are certain parameters that are to be considered that define the configuration of the antenna [15].

### 2.5.1 Radiation Pattern

Microstrip Patch Antenna has radiation patterns that can be calculated easily. The source of the radiation of the electric field at the gap of the edge of the Microstrip element and the ground plane is the key factor to the accurate calculation of the pattern for the patch antenna. Simply it can be said that the power radiated or received by the antenna is the function of angular position and radial distribution from the antenna. The radiation pattern of a generic dimensional antenna can be seen below, which consist of side lobe, black lobes, and are undesirable as they represent the energy that is wasted for transmitting antennas and noise sources at the receiving end [16].



**Figure 2.10:** Radiation pattern of generic dimensional Antenna [16]

### 2.5.2 Return Loss

The Return Loss is a parameter that shows the amount of power that is lost to the load and does not return as a reflection. When the transmitter and antenna impedance do not match, waves are reflected and this creates standing waves. Hence RL is a parameter similar to the VSWR.

$$\text{Return loss, } S_{11} = -10 \log |S_{11}|^2 \text{ or } -20 \log |\Gamma| \text{ (dB)} \quad (2.9)$$

$$\text{where, } |\Gamma| = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (2.10)$$

$|\Gamma|$  = Reflection coefficient

$V_0^-$  = the reflected voltage

$V_0^+$  = the incident voltage

$Z_L$  = Load impedance

$Z_0$  = Characteristic impedance

For perfect matching between the transmitter and the antenna,  $\Gamma = 0$  and  $RL = \infty$  which means no power would be reflected back, whereas a  $\Gamma = 1$  has a  $RL = 0$  dB, which implies that all incident power is reflected. For practical applications, a VSWR of 2 is acceptable, since this corresponds to a return loss of -9.54 dB [13].

### 2.5.3 Gain and Directivity

The gain of the antenna is the quantity which describes the performance of the antenna or the capability to concentrate energy through a direction to give a better picture of the radiation performance. This is expressed in dB, in a simple way we can say that this refers to the direction of the maximum radiation [18].



The expression for the maximum gain of an antenna is

$$G = \eta \times D \quad (2.11)$$

$\eta$  Is the efficiency of the antenna and  $D$  is the directivity.

In order to receive or transmit the power it can be chosen to maximize the radiation pattern of the response of the antenna in a particular direction.

The directivity of an antenna can be defined as the ratio of radiation intensity in a given direction from the antenna to the radiation intensity averaged in all the directions. And the gain can be known as the ratio between the amounts of energy propagated in these directions to the energy that would be propagated if there is an Omni-directional antenna. [18][19]

The directivity of the antenna depends on the shape of the radiation pattern. The measurement is done taking a reference of isotropic point source from the response. The quantitative measure of this response is known as the directive gain for the antenna on a given direction.

For any antenna, the directivity can be related to its effective area.

$$D = \frac{4\pi A_e}{\lambda^2} \quad (2.12)$$

Where,  $D$  is the directivity,

$A_e$  is the effective area and

$\lambda$  is the wavelength in meters.

#### 2.5.4 Antenna Efficiency

This property is a measure of how much electrical power supplied to an antenna is transformed into electromagnet and due to losses (imperfect dielectrics, eddy current etc.), not all energy transmitted to the antenna is radiated with this the antenna efficiency is defined as [20]:

$$\eta = \frac{P_{rad}}{P_{in}} = \frac{R_{rad}}{R_{rad} + R_l} \quad (2.13)$$

where  $\eta$  is the antenna efficiency

$P_{rad}$  is the radiated or transmitted power

$P_{in}$  is the input power

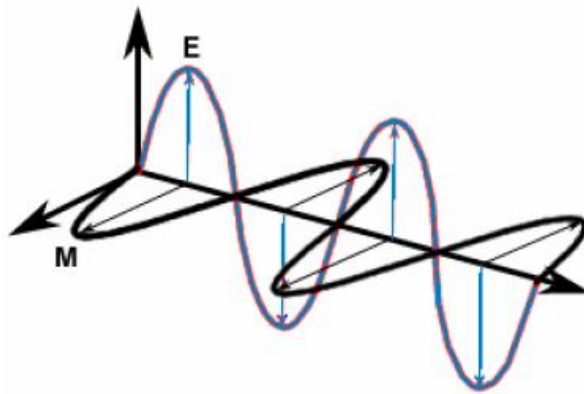
$R_{rad}$  is the radiated resistance or antenna resistance

$R_l$  is the resistance due to losses

### 2.5.5 Polarization

The polarization of the electric field vector of the radiated wave or from source Vs. time the observation of the orientation of the electric fields does also refer to the polarization. It is defined as "the property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector"[22].

The direction or position of the electric field w.r.t the ground gives the wave polarization. The common types of the polarization are circular and linear the former includes horizontal and vertical and the latter includes right hand polarization and left hand polarization.



**Figure 2.11:** linearly polarized wave [22]

It is said to be linearly polarized when the path of the electric field vector is back and forth along the line. There is also circular polarization in which the electric field vector's length is constant but rotates in a circular path [23].

### 2.5.6 Voltage Standing Wave Ratio

There should be a maximum power transfer between the transmitter and the antenna for the antenna to perform efficiently. This happens only when the impedance  $Z_{in}$  is matched to the transmitter impedance,  $Z_t$ .

In the process of achieving this particular configuration for an antenna to perform efficiently there is always a reflection of the power which leads to the standing waves, which is characterized by the Voltage Standing Wave Ratio (VSWR).

This is given by [20]:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \quad (2.14)$$

As the reflection coefficient ranges from 0 to 1, the VSWR ranges from 1 to  $\infty$ .

### 2.5.7 Bandwidth

Bandwidth can be said as the frequencies on both the sides of the center frequency in which the characteristics of antenna such as the input impedance, polarization, beamwidth, radiation pattern etc. are almost close to that of this value. As the definition goes [20] “the range of suitable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specific standard”. The bandwidth is the ratio of the upper and lower frequencies of an operation

The bandwidth increases as the substrate thickness increases (the bandwidth is directly proportional to  $h$  if conductor, dielectric, and surface-wave losses are ignored). However, increasing the substrate thickness lowers the Q of the cavity, which increases spurious radiation from the feed, as well as from higher-order modes in the patch cavity. Also, the patch typically becomes difficult to match as the substrate thickness increases

beyond a certain point (typically about  $0.05 \lambda_0$ ) [23]. This is especially true when feeding with a coaxial probe, since a thicker substrate results in a larger probe inductance appearing in series with the patch impedance. However, in recent years considerable effort has been spent to improve the bandwidth of the microstrip antenna, in part by using alternative feeding schemes.

$$B = \frac{f_H - f_L}{f_c} \times 100 \quad (2.15)$$

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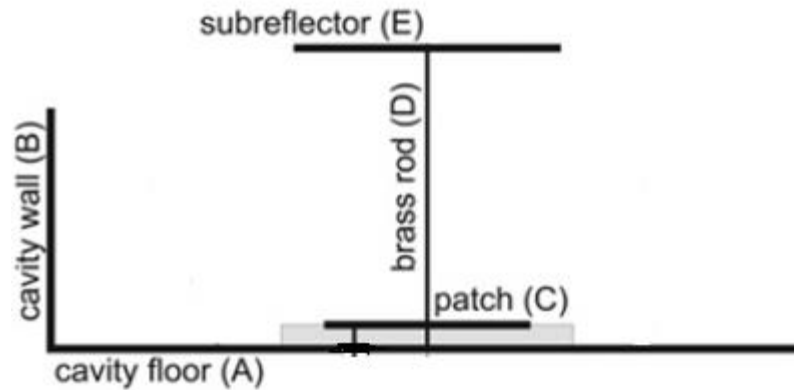
$$B = \frac{f_H - f_L}{f_c} \times 100 \quad (2.15)$$

## 2.6 Short Backfire Antenna

High-gain antennas are required for long-distance radio communications (radio-relay links and satellite links), high-resolution radars, radio-astronomy, etc. Reflector systems are probably the most widely used high-gain antennas. They can easily achieve gains of above 30 dB for microwave and higher frequencies. Reflector antennas operate on principles known long ago from geometrical optics [24].

The first RF reflector system was made by Hertz back in 1888 (a cylindrical reflector fed by a dipole). However, the art of accurately designing such antenna systems was developed mainly during the days of WW2 when numerous radar applications evolved.

A short backfire antenna is a type of a directional antenna, characterized by high gain, relatively small size, and narrow band. The short backfire antenna was first conceived by Ehrenspeck in 1960s [25], SBF antenna has received much interest for its beneficial characteristics such as compactness, simplicity of construction, high gain and so on. The conventional Short backfire antenna consists of two parallel plate reflectors with different dimensions (a big (cavity) and small reflector), spaced a distance about  $\lambda/2$  apart, the Microstrip patch was placed on the axis of the cavity reflector and the commonly feeds used includes rectangular waveguides, dipole feed and Microstrip feed line [6]. Short backfire antennas are used in some satellites and in high-frequency (short-wavelength) communication equipment (often for communication with satellites) on ships and other applications where rugged construction is an advantage. They are also used for Wireless Local Area Networks (WLANS).



**Figure 2.12:** Cross-section view Short Backfire antenna

It provides a practical alternative to a horn antenna for use as the primary feed in reflector antennas. Short backfire antennas are insensitive to the polarization of the feed which means that the feed can be linearly polarized in any direction or circularly polarized. Linear polarization is achieved using a single dipole element or an open ended waveguide [26]. Circular polarization is achieved using a crossed dipole or similar feed. The backfire antenna operates in a resonant mode. This means that no simple theories are available to predict the performance, and most of the published data concerned with the short backfire antenna reports experimental data due to the difficulty of theoretically modeling the antenna. Short backfire antennas have traditionally been designed on a 'cut and try' basis which is both costly and time consuming. Over the years Various forms of feed elements were used in exciting the short backfire antenna and many improvements were achieved by trying different shapes and sizes of reflectors or adding a rim to the back reflector [alrashid2] Among other structures implemented in exciting the short backfire structure were the open-ended waveguides which are suitable for applications in the microwave frequency bands. Waveguide excitation structure for SBA may improve impedance bandwidth but it is bulky and involves complex manufacturing process [25-27]. From extensive studies of the near field of the SBF antenna we know that SBF antenna operation is characterized by multiple reflections of electromagnetic wave between the two planar reflectors subreflector and big reflector, and that the space between subreflector and big reflector acts as an open resonant cavity that radiates most of

its energy from a virtual aperture between the edges of subreflector and cavity wall, extending somewhat outside the cavity wall. The best pattern performance and highest efficiency is obtained from a circular reflector because the entire antenna structure is symmetric, but square or other rectangular reflector shapes can also be used with only a small sacrifice in gain and sidelobe level. However because of its compact construction and high performance, the short backfire antenna is very popular today. It is equivalent in gain to a 10-times-longer conventional Yagi antenna [28]. Design of short backfire antenna requires compliance with one important criterion. That is the requirement that the far-field radiation patterns in the primary planes should be as symmetric as possible to provide equal illumination of the reflector in all directions to obtain higher gain [30]. By choosing an appropriate set of geometric parameters, the short backfire antenna is capable of satisfying this requirement. The height of the cavity rim is found to be instrumental in the control of the levels of the side lobes.

## **2.7 Parasitic Elements Requirement**

Narrowing the E-plane radiation pattern main lobe would have the advantages of increasing the gain, decreasing the side lobe level and, for a circularly polarized antenna, decrease the axial ratio and polarization losses. It has been shown previously that the principal plane beamwidth of a dipole fed SBA could be controlled by varying the cavity wall height [31]. This method was unsuitable for a man portable application where high-cavity walls forming an enclosed structure were highly desirable for safety reasons. The cavity wall height has been used to equalize the E-plane and H-plane beamwidth in the past, but reducing the cavity wall height from 102 to 50 mm ( $0.25\lambda$ ) here would have led to a loss in peak gain according to the parametric study of the effects of cavity wall height upon peak gain.

### 2.7.1 Effect of cavity profile on aperture distribution

Comparison of the  $E_y$  amplitude distributions across the mouth of a  $2.5\lambda$ , diameter,  $0.55\lambda$  depth, inset fed, cylindrical cavity without sub reflector to variations with  $0.4\lambda$  and  $0.5\lambda$  sub reflectors, shows that the power was more evenly distributed across the cavity mouth with the sub reflectors, Figure 3.20. Without the sub reflectors, more power was concentrates at the center of the cavity mouth. The difference of  $E_y$  amplitude between the cavity center and edges was about -22dB for both planes, and about -7dB from center to  $\pm 0.5\lambda$ , ( $\pm 10\text{mm}$ ), Figure 3.20. Addition of a  $0.4\lambda$  diameter sub reflectors gave a center to edge difference of about -24dB for the H-plane and -32dB for the E-plane. Perhaps a little more significantly, the center to  $\pm 0.5\lambda$  was about -6.5dB. Thus, adding  $0.4\lambda$  diameter subreflectors reduced the amount of power at the cavity edges while broadening the power distribution at the center a little. Adding the  $0.5\lambda$  diameter sub reflector had a more noticeable effect. The center to edge difference was -32dB in the H-plane and -14dB in the E-plane, while the center to  $\pm 0.5\lambda$ , difference was about -4dB in the H-plane and -6dB in the E-plane, Figure 3.20. Addition of the  $0.5\lambda$ , sub reflector had a different effect upon either plane, but the overall power distribution was more even across the cavity mouth. As seen above, this brought about a marked increase in directivity [33].



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